Higgs Couplings and Precision Electroweak Data

Brian Batell
University of Chicago

with Stefania Gori and Lian-Tao Wang
arXiv:1209.6382

Fermilab
February 21, 2013

Motivation

LHC experiments have discovered a new particle!

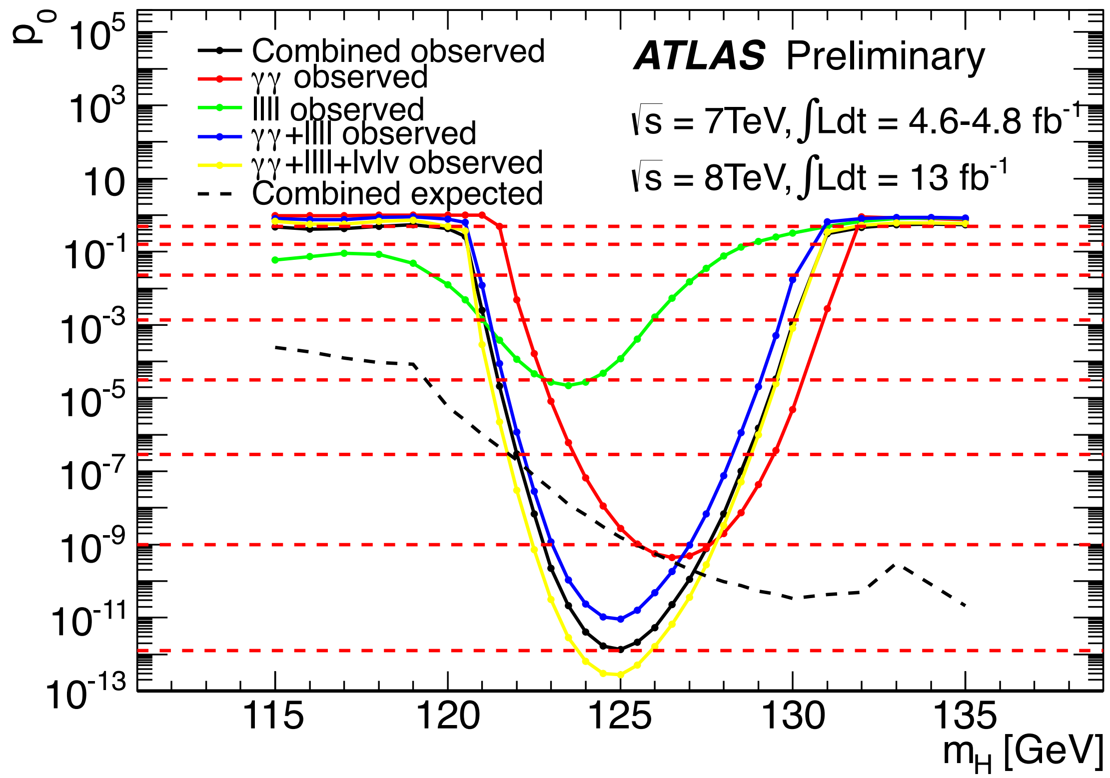
- Higgs-like state, mass ~ 126 GeV:
- Light, as suggested by precision electroweak data...
- Signal strength in diphoton channel a little high...
- But, statistics are low, certainly consistent with SM

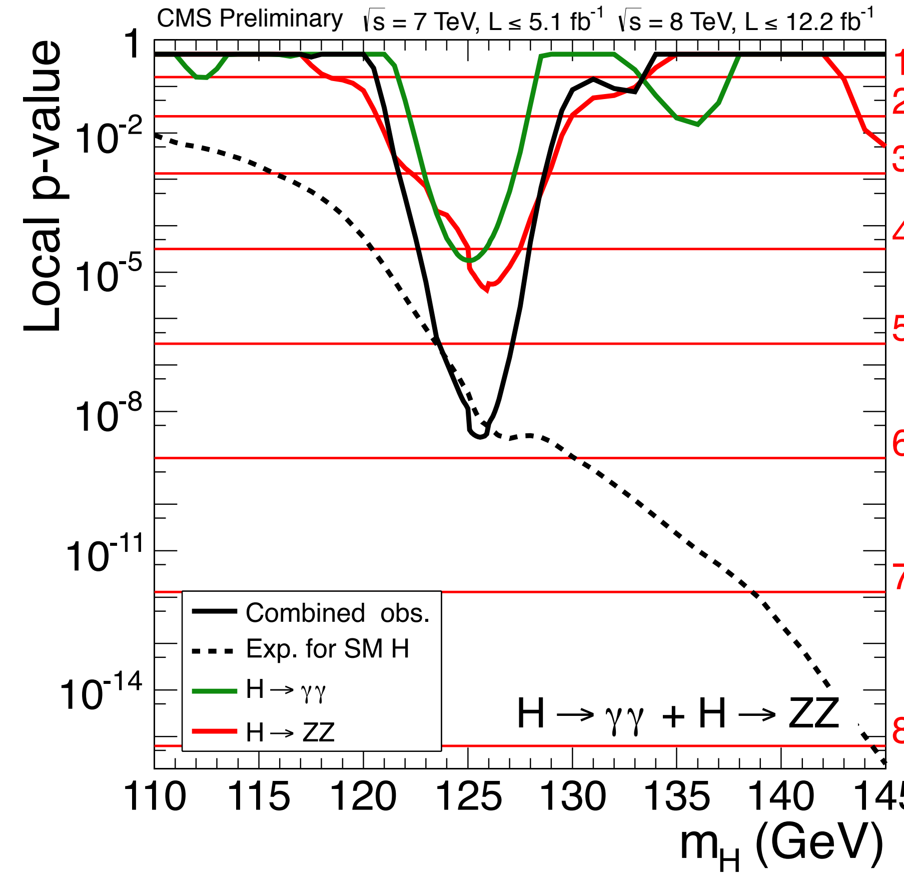
Precision Electroweak Data

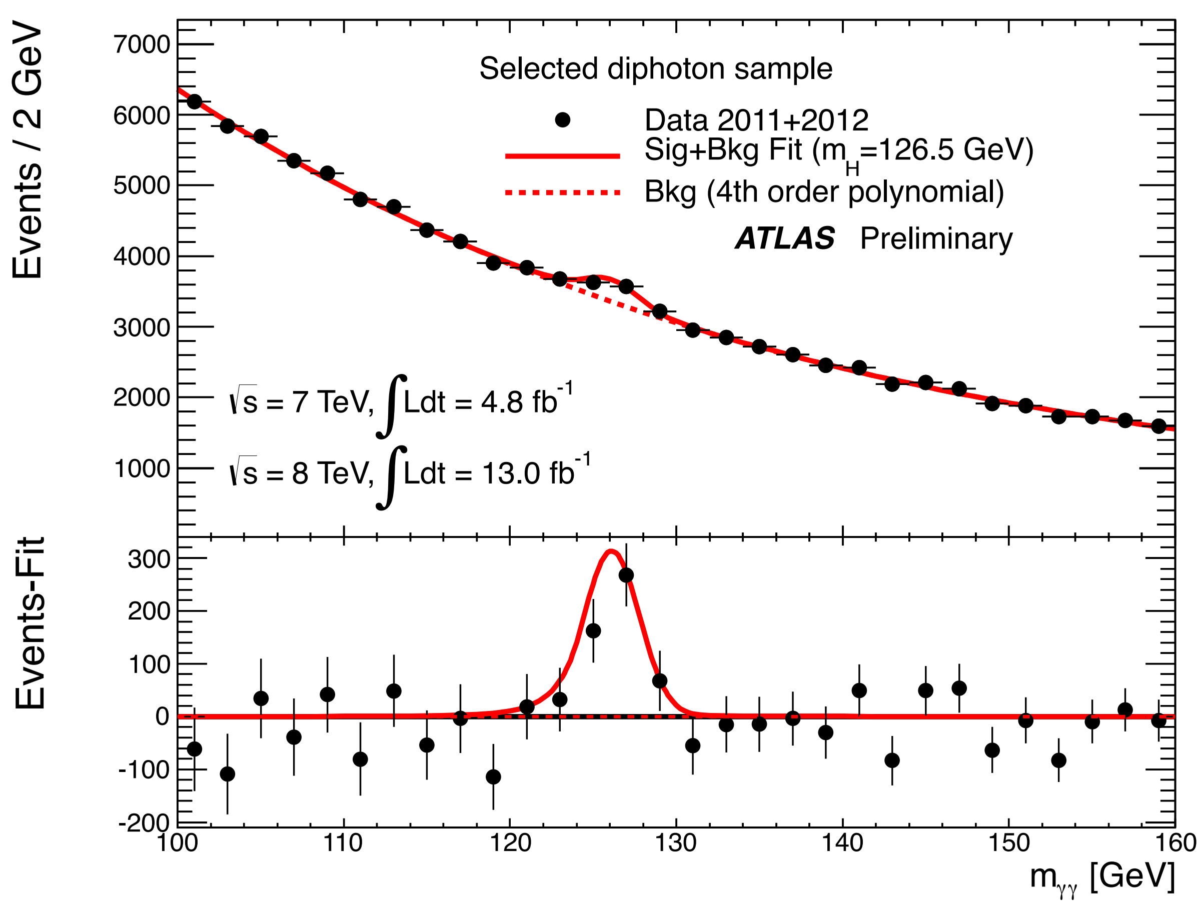
- Most observables are in agreement with SM predictions
- A persistent discrepancy: A^b_{FB} at Z-pole; (2.6σ)
- A new discrepancy (new theory calculation): R_b (2.4σ)
- Tension with 126 GeV?

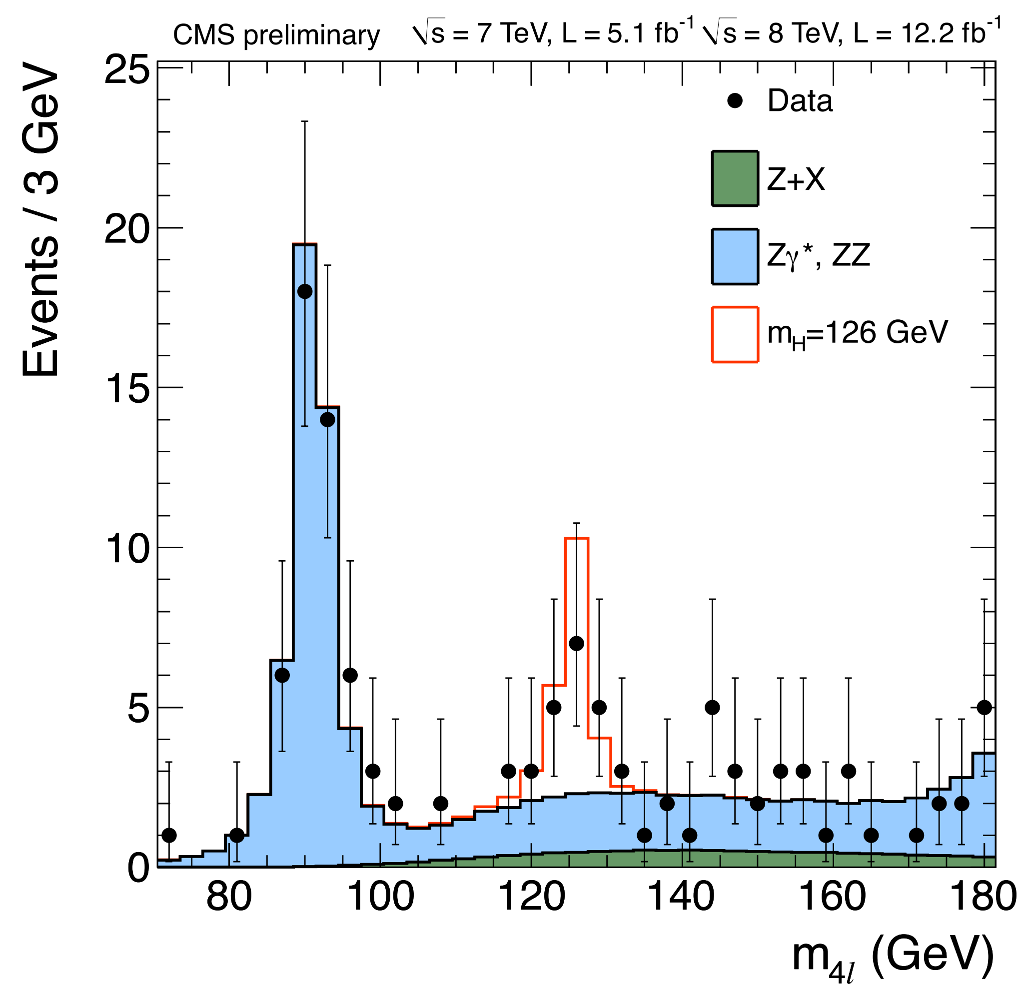
Let's explore the possible connections between Higgs physics and A^b_{FB}, R_b

Higgs!

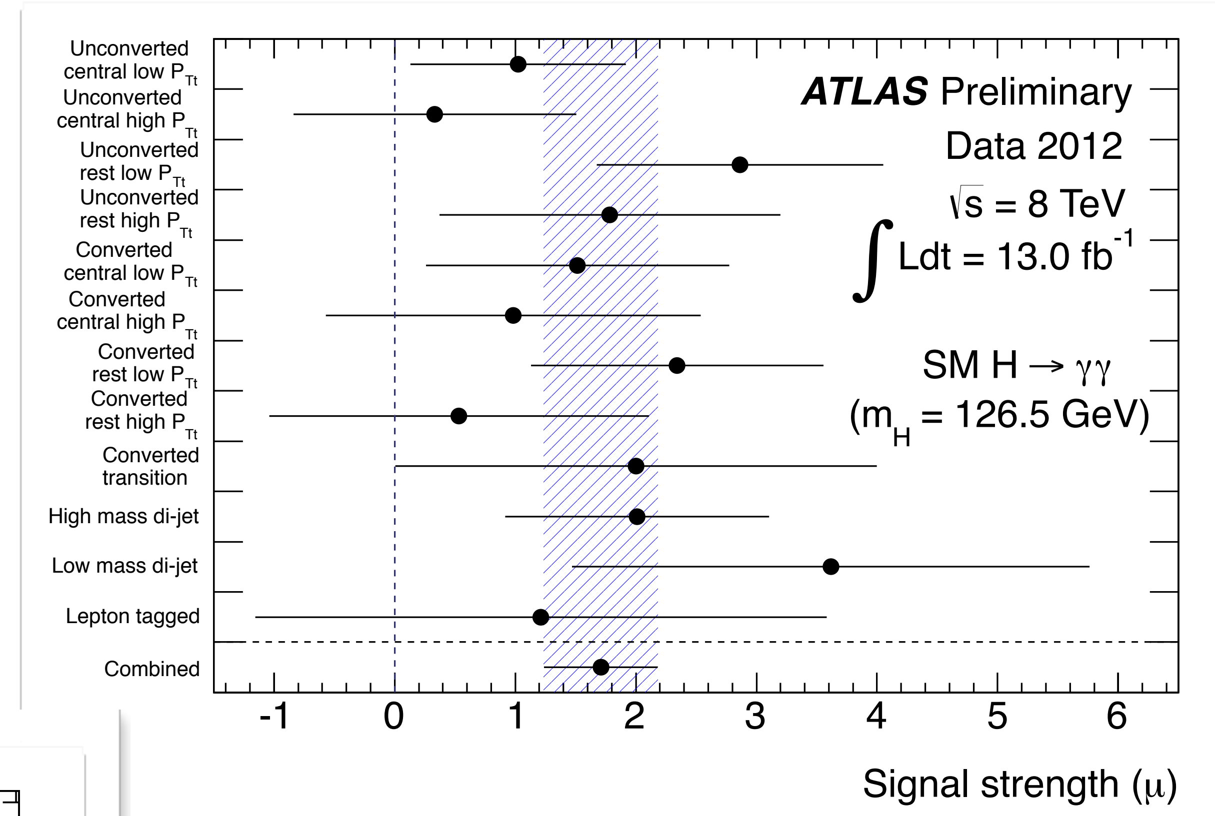

ATLAS Preliminary
Combined observed
γγ observed
llll observed
γγ+llll observed
γγ+llll+lνlν observed
Combined expected
√s = 7TeV, ∫Ldt = 4.6-4.8 fb⁻¹
√s = 8TeV, ∫Ldt = 13 fb⁻¹
p0
mH [GeV]

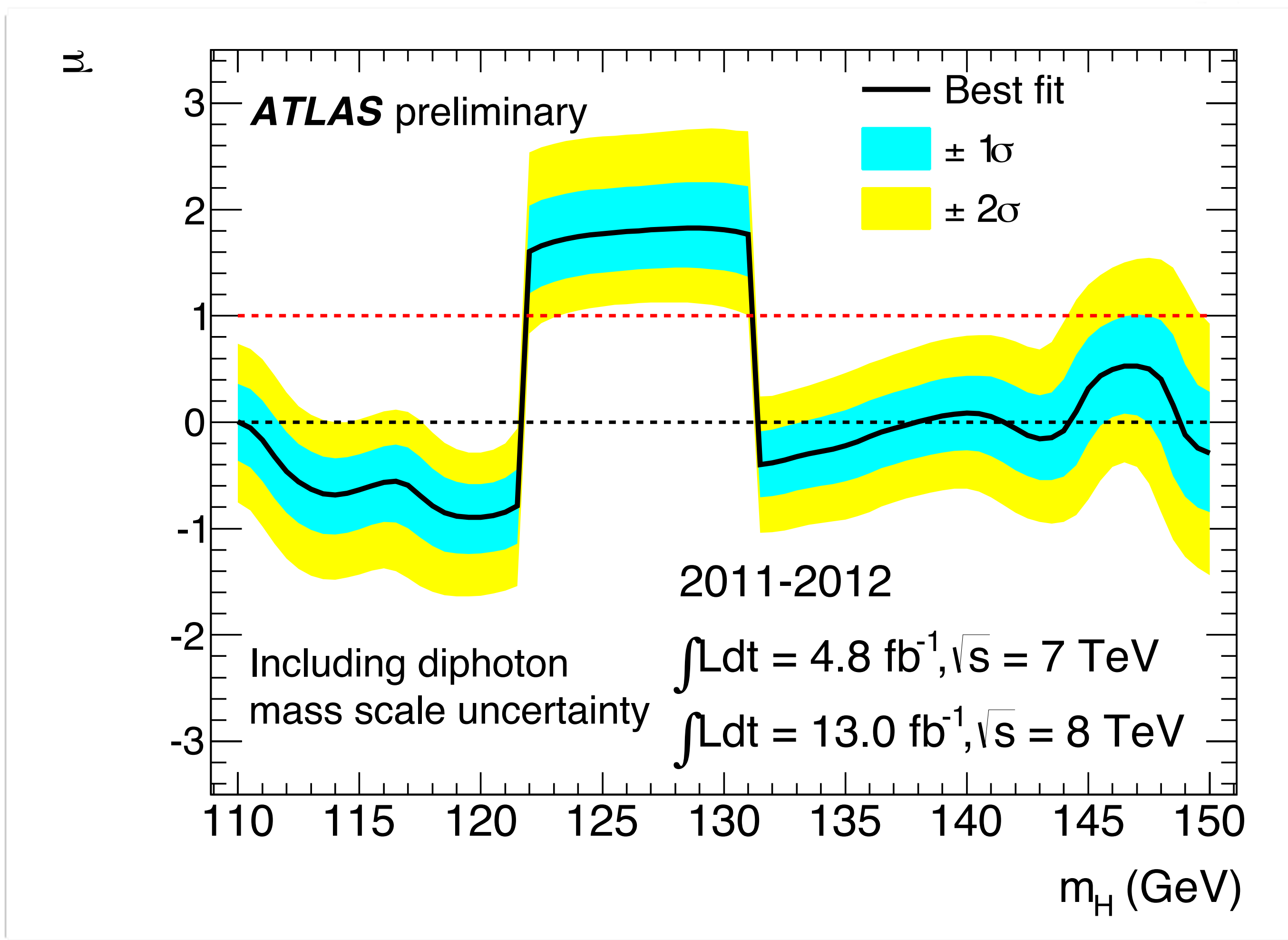

CMS Preliminary √s = 7 TeV, L ≤ 5.1 fb⁻¹ √s = 8 TeV, L ≤ 12.2 fb⁻¹
Local p-value
Combined obs.
Exp. for SM H
H → γγ
H → ZZ
H → γγ + H → ZZ
mH (GeV)


Selected diphoton sample
Data 2011+2012
Sig+Bkg Fit (mH=126.5 GeV)
Bkg (4th order polynomial)
ATLAS Preliminary
√s = 7 TeV, ∫Ldt = 4.8 fb⁻¹
√s = 8 TeV, ∫Ldt = 13.0 fb⁻¹
Events / 2 GeV
Events-Fit
mγγ [GeV]

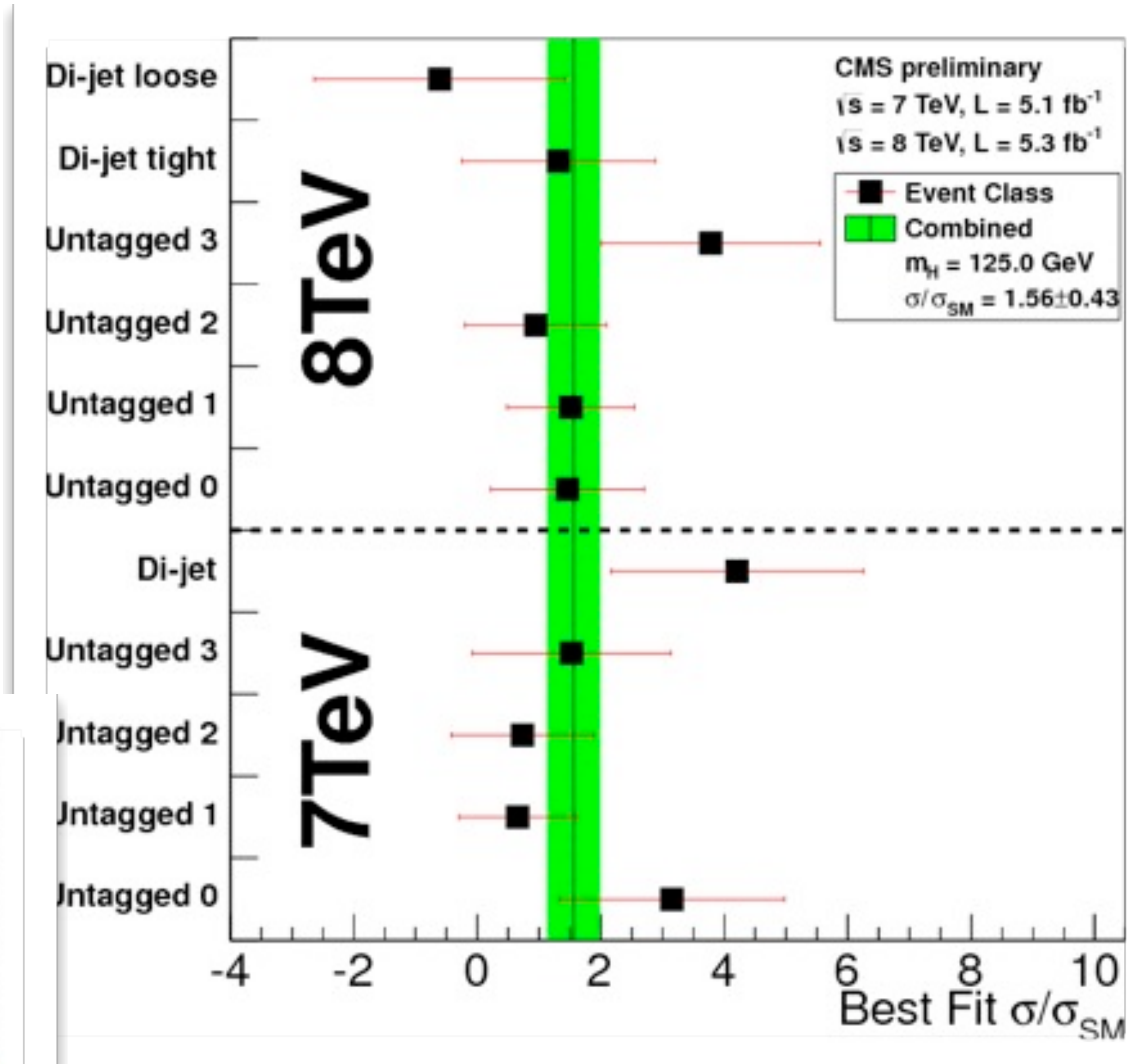

CMS preliminary √s = 7 TeV, L = 5.1 fb⁻¹ √s = 8 TeV, L = 12.2 fb⁻¹
Data
Z+X
Zγ*, ZZ
mH=126 GeV
Events / 3 GeV
m4l (GeV)

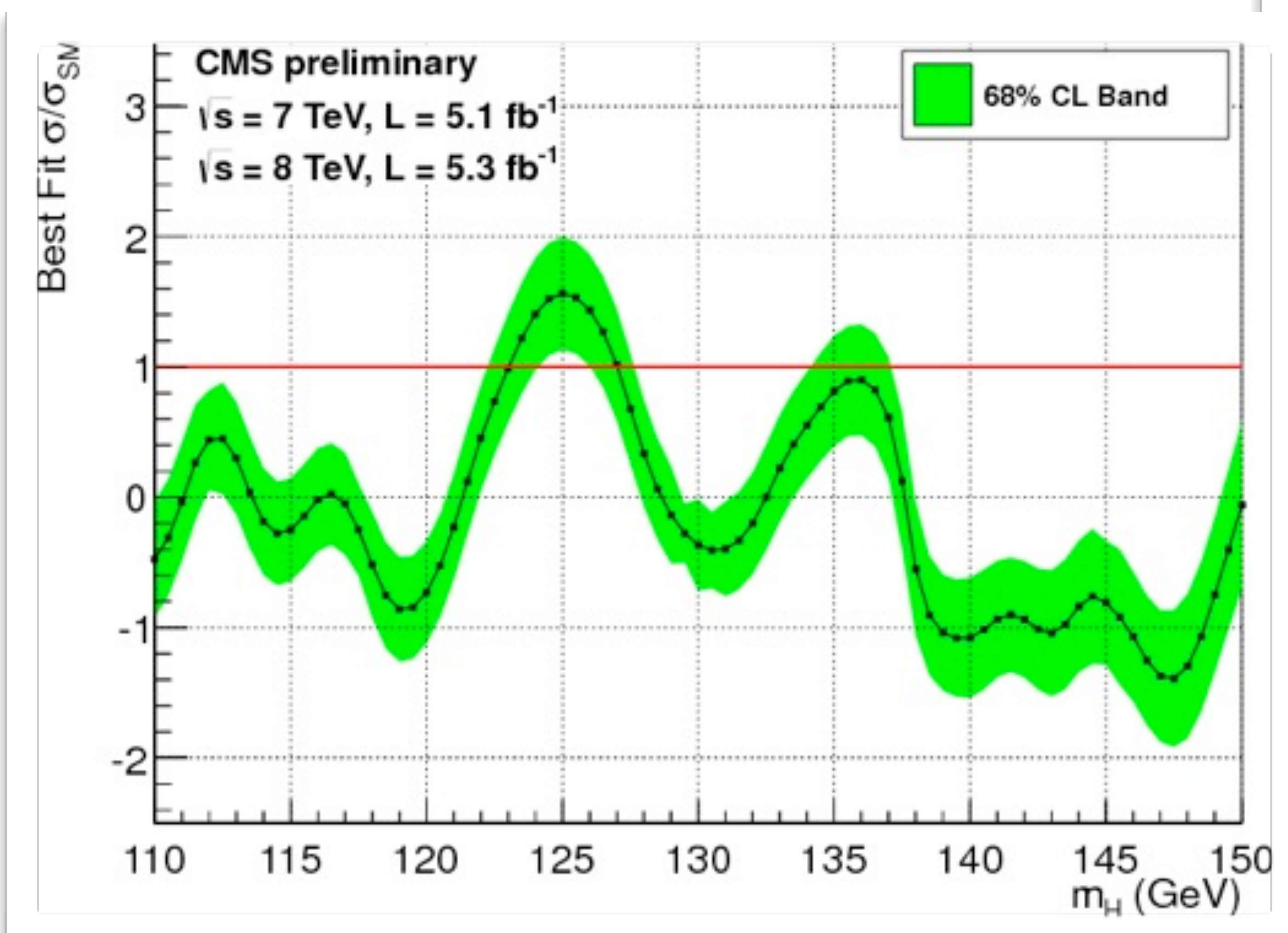
A few too many photons?





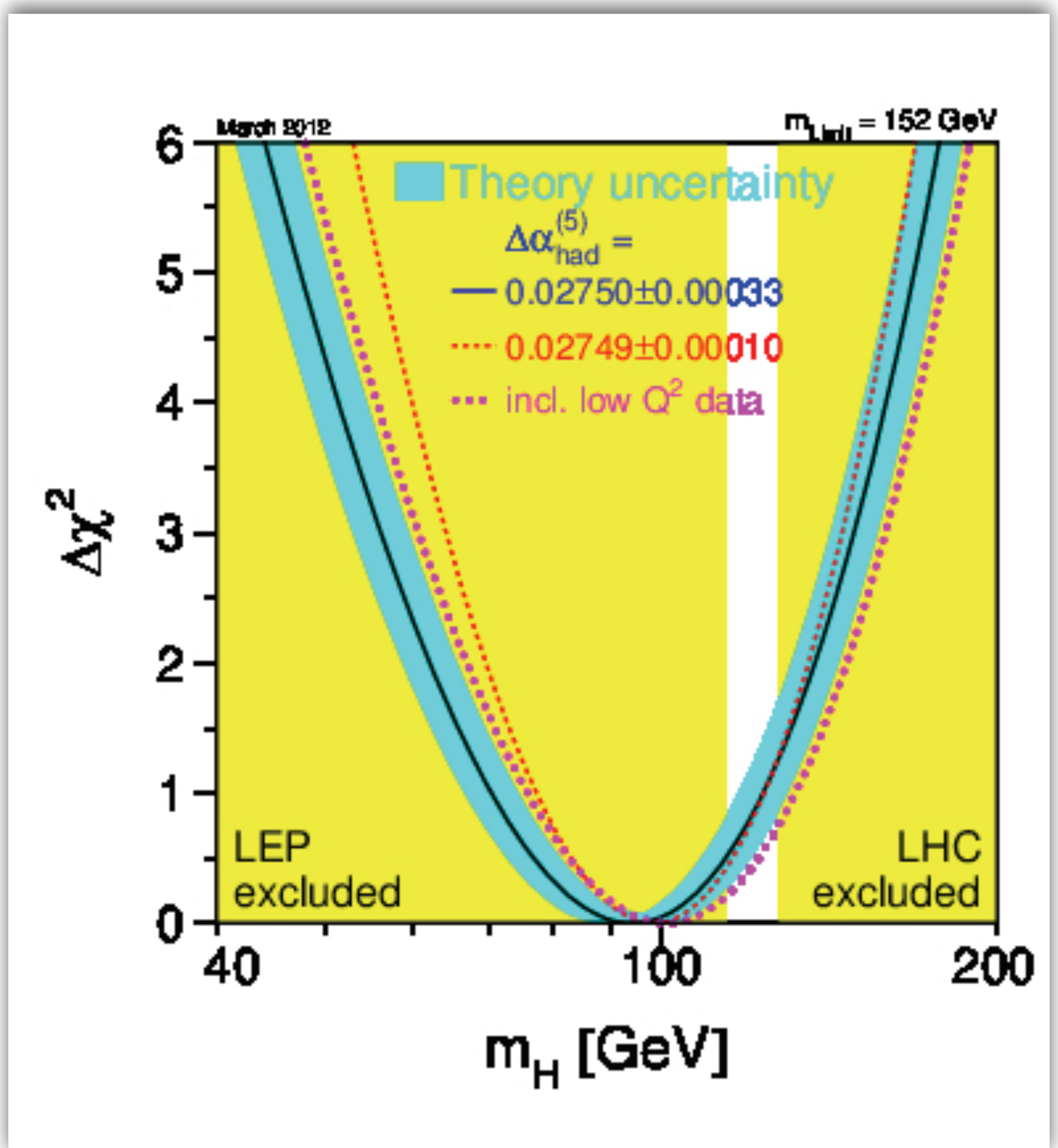
A few too many photons?

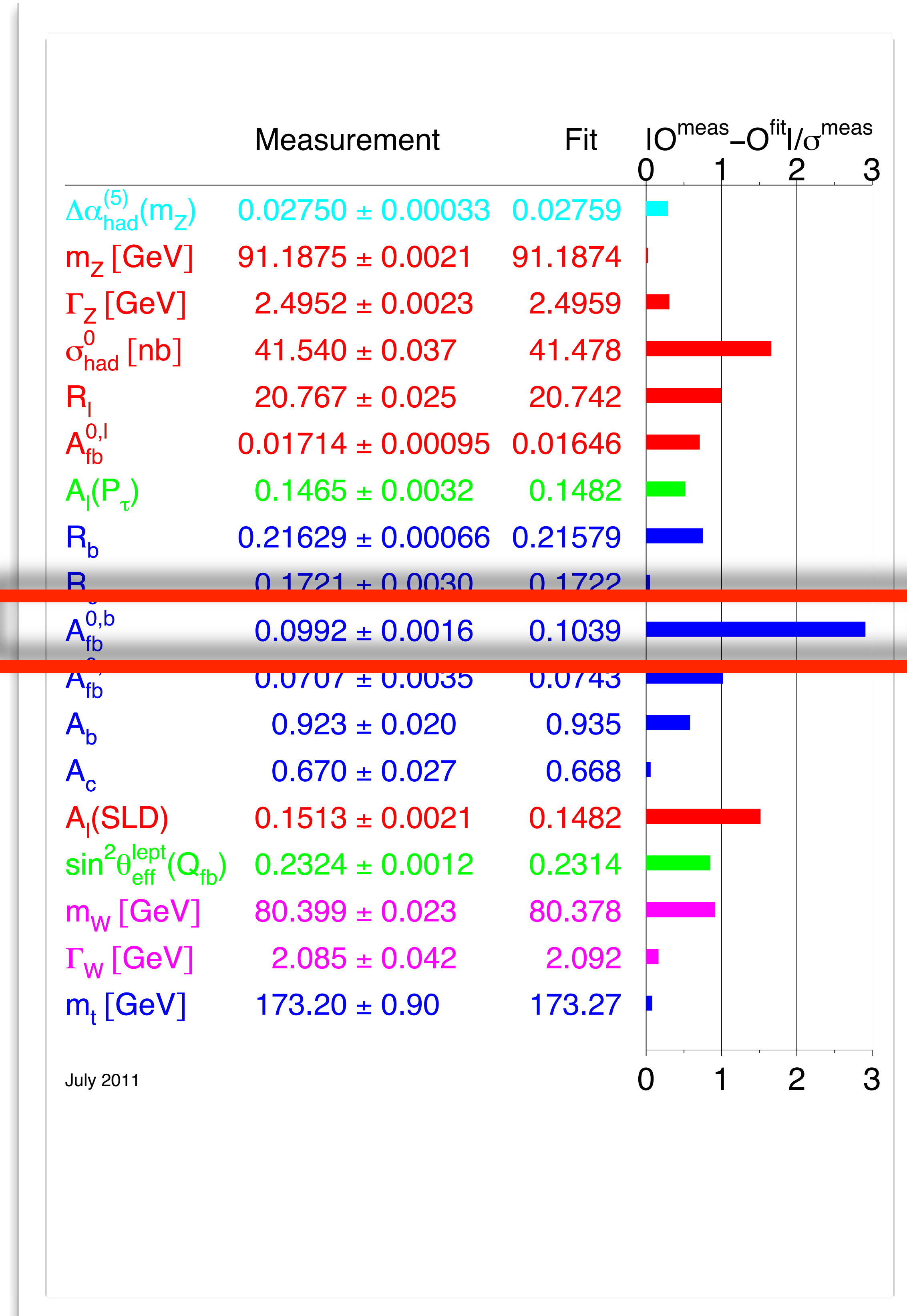




Note: CMS has not updated the diphoton analysis with the full dataset

Precision Electroweak Data (circa December 2011)





[LEP EWWG]

Global fits of the Standard Model

PDG : $\chi^2/\mathrm{dof} = 45/42 \quad (35\%)$ (Dec `12)

[Erler, Langacker]

LEP EWWG (ZFitter): $\chi^2/\mathrm{dof} = 17.3/13 \quad (19\%)$ (Dec `10)

[arXiv:1012.2367]

GFitter: $\chi^2/\mathrm{dof} = 16.7/13 \quad (21\%)$ (July `11)

http://gfitter.desy.de/

Since then:

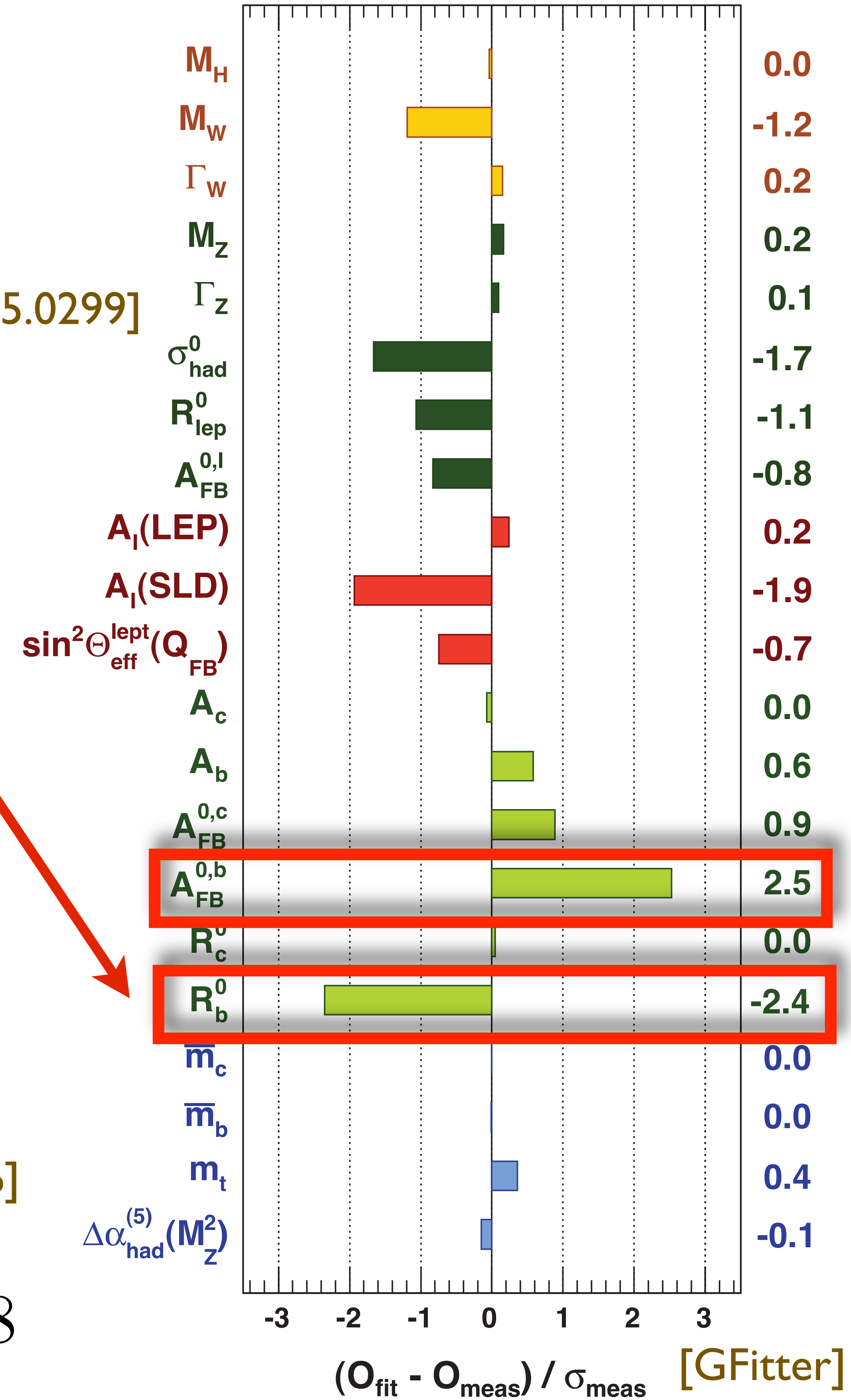
1. Electroweak two loop corrections for R_b [Freitas, Huang, 1205.0299]

Now $> 2\sigma$ discrepancy!

2. Higgs discovered!
Higgs mass directly measured

Global fit (Gfitter): [arXiv:1209.2716]

$$\chi^2/\text{d.o.f.} = 21.8/14, \qquad p = 0.08$$



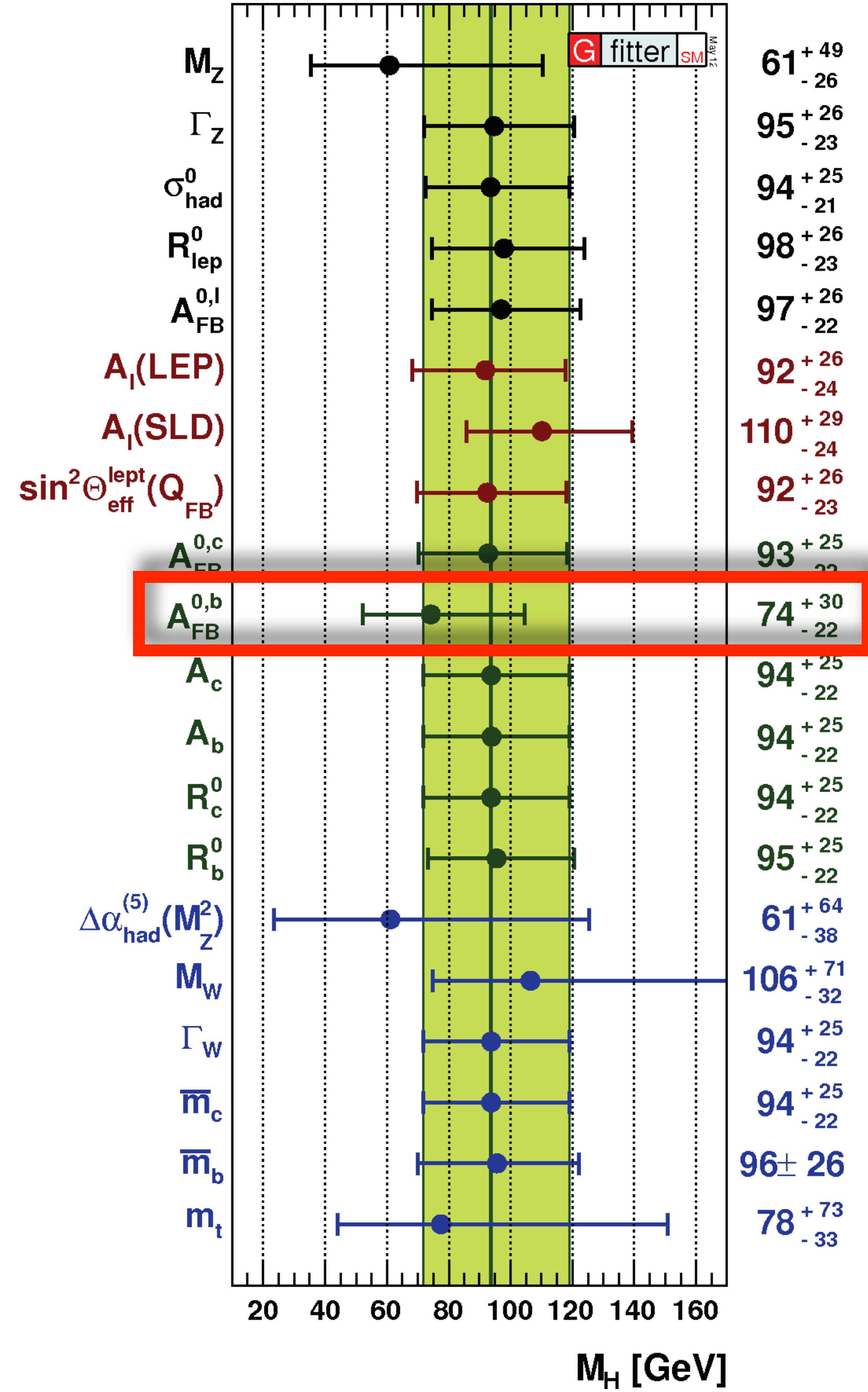
A puzzle?

Could very well be New Physics altering A^b_{FB}, R_b

However, $2-3\sigma$ discrepancies come and go all the time!

But ... if A^b_{FB} attributed to experimental error, electroweak fit prefers a very light Higgs, in tension with LEP bound

[Chanowitz '01]



[GFitter]

Can A_{FB}^b, R_b and $\gamma\gamma$ rate be due to same underlying new physics?

A_{FB}^{b}

$$\mathcal{L} \supset \frac{g}{c_W} Z_\mu \bar{b}(g_{Lb}P_L + g_{Rb}P_R)b$$

Consider the process

$$e^+e^- \to \gamma, Z, \to b\bar{b}$$

Forward, backward cross sections:

$$\sigma_{F,B} = \mp \int_0^{\pm 1} \frac{d\sigma}{d\cos\theta} d\cos\theta$$

Polarized cross sections:

$$\sigma_{LL} \equiv \sigma(e_L^+ e_L^- \to b_L \bar{b}_L), \text{ etc.}$$

Forward-backward asymmetry:

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{3}{4} \frac{\sigma_{LL} + \sigma_{RR} - \sigma_{LR} - \sigma_{RL}}{\sigma_{LL} + \sigma_{RR} + \sigma_{LR} + \sigma_{RL}}$$

On Z-pole:

$$\sigma_{LL} \propto \frac{g_{Le} g_{Lb}}{m_Z \Gamma_Z} \text{, etc.}$$

$$A_{FB} = \frac{3}{4} \frac{g_{Le}^2 - g_{Re}^2}{g_{Le}^2 + g_{Re}^2} \frac{g_{Lb}^2 - g_{Rb}^2}{g_{Lb}^2 + g_{Rb}^2}$$

R_b

$$\mathcal{L} \supset \frac{g}{c_W} Z_\mu \bar{b}(g_{Lb} P_L + g_{Rb} P_R) b$$

Z boson partial width: $\Gamma(Z \to \psi_i \bar{\psi}_i) \simeq \frac{g^2}{24\pi c_W^2}(g_{Li}^2 + g_{Ri}^2) M_Z$

$$\Rightarrow \quad R_b \equiv \frac{\Gamma(Z \to b\bar{b})}{\Gamma(Z \to \text{hadrons})} \simeq \frac{g_{Lb}^2 + g_{Rb}^2}{\sum_q [g_{Lq}^2 + g_{Rq}^2]}$$

Note: both A_{FB}^b, R_b depend on couplings $g_{Lb}, \quad g_{Rb}$

Suggests common resolution: tree-level shifts in $Zb\bar{b}$

Modify $Zb_R\bar{b}_R$ coupling

[Haber, Logan '99]
[Choudhury, Tait, Wagner '01]

$$\mathcal{L} \supset \frac{g}{c_W} Z_\mu \bar{b}(g_{Lb}P_L + g_{Rb}P_R)b$$

$$g_{Lb} = -\frac{1}{2} + \frac{1}{3}s_w^2 \approx -0.43$$
$$g_{Rb} = \frac{1}{3}s_w^2 \approx 0.0771$$

Goal: shift A_{FB}^b and R_b

$$A_{FB} = \frac{3}{4}\frac{g_{Le}^2 - g_{Re}^2}{g_{Le}^2 + g_{Re}^2}\frac{g_{Lb}^2 - g_{Rb}^2}{g_{Lb}^2 + g_{Rb}^2} \qquad R_b \equiv \frac{\Gamma(Z \to b\bar{b})}{\Gamma(Z \to \text{hadrons})} \simeq \frac{g_{Lb}^2 + g_{Rb}^2}{\sum_q [g_{Lq}^2 + g_{Rq}^2]}$$

Z-pole data allows 4 solutions in $(\delta g_{Lb}, \delta g_{Rb})$, off-peak data for A_{FB}^b eliminate 2 possible solutions

Data prefers a bigger shift in δg_{Rb}, smaller shift in δg_{Lb}

Possible resolutions of A_{FB}^b, R_b discrepancies

1. New physics directly alters A_{FB}^b, R_b

- Focus on tree level shifts to $Zb\bar{b}$ couplings

2. A_{FB}^b, R_b due to measurement errors

- Remove measurements from EW fit. Is there tension with 125 GeV Higgs?

How compelling are each of these resolutions?

To answer this question, we have performed a global fit to the precision electroweak data

Possible resolutions of A_{FB}^b, R_b discrepancies

1. New physics directly alters A_{FB}^b, R_b

- Focus on tree level shifts to $Zb\bar{b}$ couplings

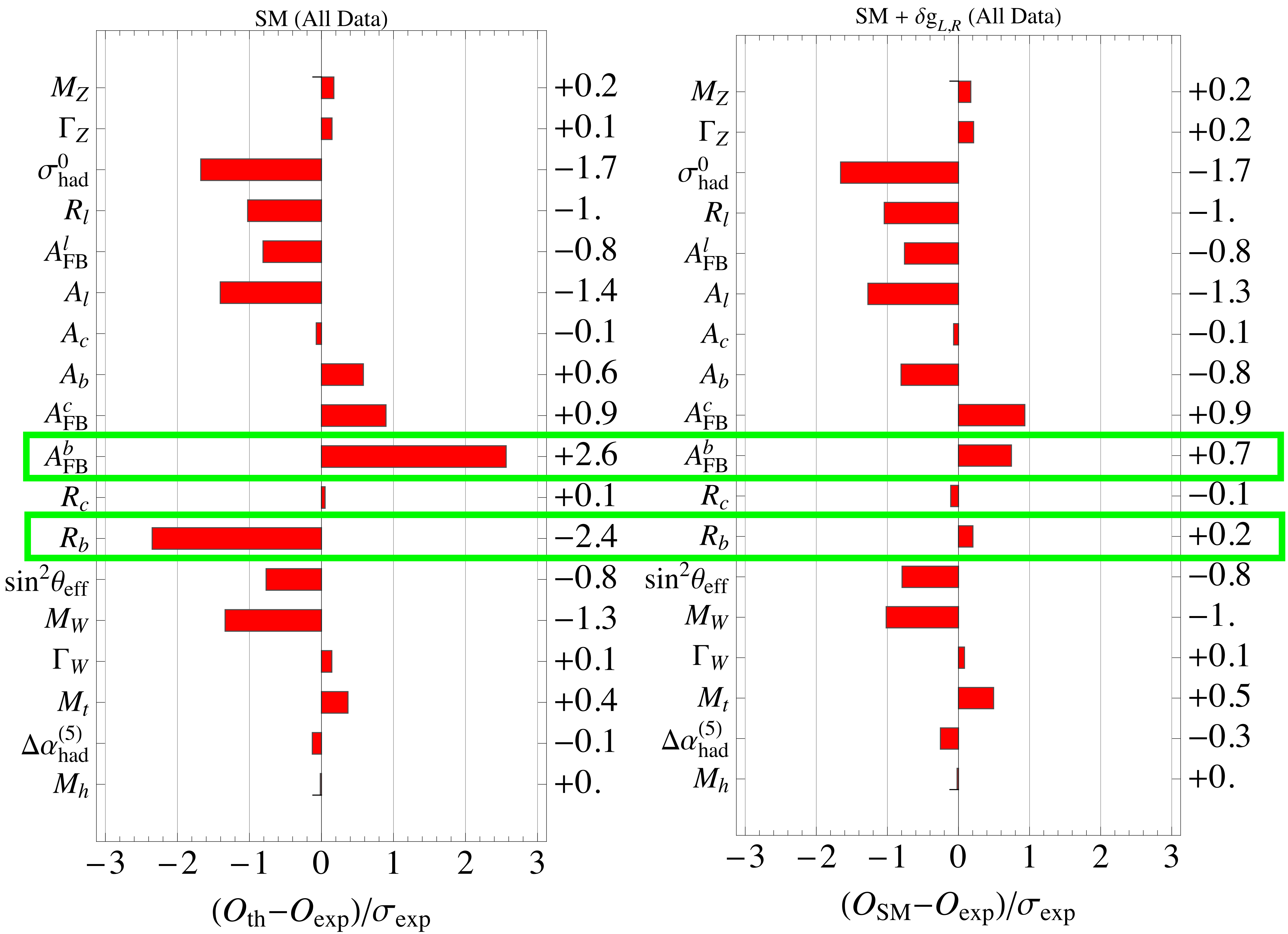
Focus on this possibility

(more on 2nd option in backup)

New physics in A_{FB}^b, R_b ?

Standard Model:	$\chi^2/\mathrm{d.o.f} = 20.5/13, \quad p = 0.08$
SM + $\delta g_{L,R}$:	$\chi^2/\mathrm{d.o.f} = 9.6/11, \quad p = 0.57$

Fit with non-universal $Z\bar{b}b$ couplings much improved!

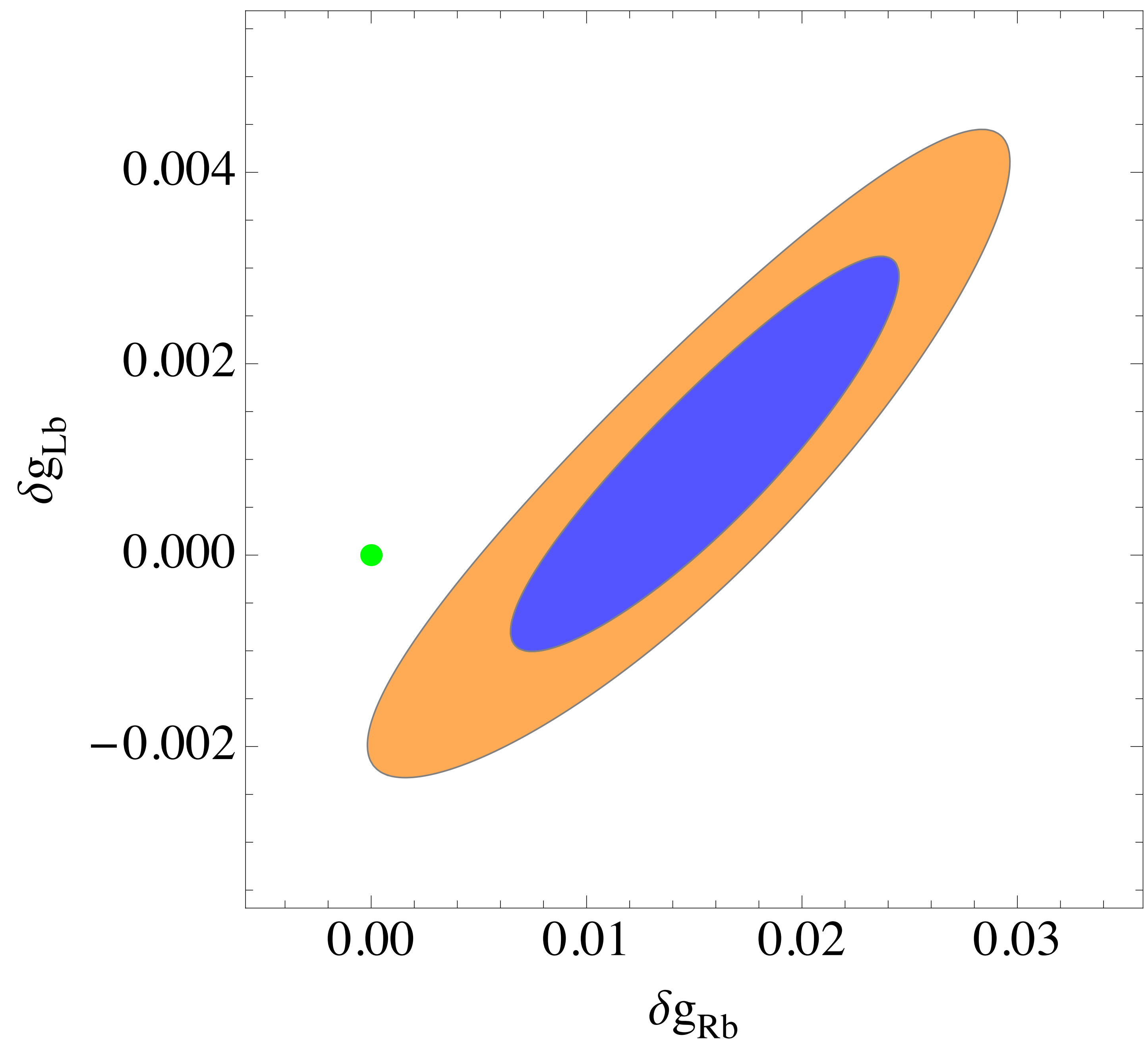


SM (All Data)
SM + $\delta g_{L,R}$ (All Data)
M_Z +0.2 +0.2
Γ_Z +0.1 +0.2
$\sigma^0_{\rm had}$ −1.7 −1.7
R_l −1. −1.
$A^l_{\rm FB}$ −0.8 −0.8
A_l −1.4 −1.3
A_c −0.1 −0.1
A_b +0.6 −0.8
$A^c_{\rm FB}$ +0.9 +0.9
$A^b_{\rm FB}$ +2.6 +0.7
R_c +0.1 −0.1
R_b −2.4 +0.2
$\sin^2\theta_{\rm eff}$ −0.8 −0.8
M_W −1.3 −1.
Γ_W +0.1 +0.1
M_t +0.4 +0.5
$\Delta\alpha^{(5)}_{\rm had}$ −0.1 −0.3
M_h +0. +0.
−3 −2 −1 0 1 2 3
$(O_{\rm th}-O_{\rm exp})/\sigma_{\rm exp}$
$(O_{\rm SM}-O_{\rm exp})/\sigma_{\rm exp}$

Best-fit region:

$$\delta g_{Lb} \sim 0.001 \pm 0.001$$

$$\delta g_{Rb} \sim 0.015 \pm 0.005$$



See also: [Choudhury, Tait, Wagner '01]
[Kumar, Shepard, Tait, Vega-Morales '10]

New physics models for A_{FB}^b, R_b

Beautiful Mirrors [Choudhury, Tait, Wagner '01]

Basic idea: Mix new vector-like quark with bottom quark

$$\mathcal{L} \supset -(\bar{b}'_L \;\; \bar{B}'_L)\begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix}\begin{pmatrix} b'_R \\ B'_R \end{pmatrix} + \text{h.c.}$$

Diagonalize mass matrix via rotations of $b_{i(L,R)}$, with angles $\theta_{L,R}$

Z boson interactions: $$\mathcal{L} \supset \frac{g}{c_w} Z_\mu \sum_{ij} \bar{b}_i \gamma^\mu (L_{ij} P_L + R_{ij} P_R) b_j$$

Shifts in $Z\bar{b}b$ couplings:

$$\boxed{\delta g_{Lb} = \left(t_{3L} + \frac{1}{2}\right) s_L^2, \qquad \delta g_{Rb} = t_{3R} s_R^2,}$$

Singles out 3 vector-like representations:

$$\Psi_{L,R} \sim (3,2,1/6), (3,2,-5/6), (3,3,2/3)$$

Focus on $\Psi \sim (3,2,-5/6) \sim \begin{pmatrix} B \\ X \end{pmatrix}$ $\qquad Q_X = -4/3$

$$t^B_{3R} = \frac{1}{2} \;\Rightarrow\; \delta g_{Rb} = \frac{1}{2} s_R^2 = 0.015 \;\Rightarrow\; s_R \sim 0.17$$

(small mixing)

Minimal model:

$$-\mathcal{L} \supset y_1 \bar{Q} H b_R + y_2 \bar{\Psi}_L H^\dagger b_R + M \bar{\Psi}_L \Psi_R + \text{h.c.}\ .$$

$$= (\bar{b}_L \;\; B_L) \left[\begin{pmatrix} Y_1 & 0 \\ Y_2 & M \end{pmatrix} + \frac{h}{v} \begin{pmatrix} Y_1 & 0 \\ Y_2 & 0 \end{pmatrix} \right] \begin{pmatrix} b_R \\ B_R \end{pmatrix}, \qquad Y_i \equiv \frac{y_i v}{\sqrt{2}}$$

shifts: $\delta g_{Rb} \simeq \dfrac{Y_2^2}{2M^2} \;\Rightarrow\; Y_2 \sim 0.17 M$

- Small oblique parameters S, T [Peskin, Takeuchi `90, `92]
- Light Higgs, heavy mirror quarks preferred by EW data

Higgs physics

see also Wagner, Morrissey '03

Main effects in Higgs production and decay:

1. Rotations shift in the $hb\bar{b}$ vertex: $\mathcal{L}_{hbb} \simeq -c_R^2 \dfrac{m_b}{v} h\bar{b}b$

⇨ Partial width $h \to b\bar{b}$ suppressed by c_R^4

2. Heavy quark B contributes to $h \to gg$ and $h \to \gamma\gamma$

can be characterized in terms of ratios $r_b, r_g, r_\gamma,\quad r_i \equiv \dfrac{\Gamma(h \to i)}{\Gamma(h \to i)_{\rm SM}}$

But, mixing angle and Yukawas are small in the minimal model

⇨ Higgs boson is SM-like (10% shifts at most)

Extension of the minimal model:

[Choudhury, Tait, Wagner '01]

- One can further improve the EW fit by adding an SU(2) singlet quark $\hat{B} \sim (3,1,-1/3)$ that mixes with the bottom

- This causes a shift $\delta g_{Lb} \sim 0.001$

- Mass matrix:

$$\mathcal{M}_B = \begin{pmatrix} Y_1 & 0 & Y_2 \\ Y_3 & M_1 & Y_4 \\ 0 & Y_5 & M_2 \end{pmatrix},$$

δg_{Lb}

δg_{Rb}

Higgs properties

- Large Y_4, Y_5 can alter Higgs rates, but also cause large custodial symmetry breaking; $\Rightarrow$ custodial extension

A custodial extension:

- SM quantum numbers:

$$\Psi^T_{L,R} = (B, X) \sim (3, 2, -5/6),$$
$$\hat{B}_{L,R} \sim (3, 1, -1/3),$$
$$\hat{X}_{L,R} \sim (3, 1, -4/3).$$

- Quantum numbers under $SU(2)_L \times SU(2)_R \times U(1)_X$

$$\Psi^T_{L,R} = (B, X) \sim (2, 1)_{-5/6}$$
$$\hat{\Psi}^T_{L,R} = (\hat{B}, \hat{X}) \sim (1, 2)_{-5/6}$$

- Such representations can find motivation in composite Higgs models

[Agashe, Contino, Da Rold, Pomarol '06]

Lagrangian

$$
\begin{aligned}
-\mathcal{L} \supset\ & M_1 \bar{\Psi}'_L \Psi'_R + M_2 \bar{\hat{B}}'_L \hat{B}'_R + M_3 \bar{\hat{X}}'_L \hat{X}'_R \\
& + y_1 \bar{Q}'_L H b'_R + y_2 \bar{Q}'_L H \hat{B}'_R \\
& + y_3 \bar{\Psi}'_L \tilde{H} b'_R + y_4 \bar{\Psi}'_L \tilde{H} \hat{B}'_R \\
& + y_5 \bar{\hat{B}}'_L \tilde{H}^\dagger \Psi'_R \\
& + y_6 \bar{\Psi}'_L H \hat{X}'_R \\
& + y_7 \bar{\hat{X}}'_L H^\dagger \Psi'_R
\end{aligned}
$$

- Custodial limit: $M_2 = M_3,\ y_4 = y_6,\ y_5 = y_7$

- Note that $y_1,\ y_2,\ y_3$ explicitly break custodial symmetry, but only small values required to obtain required shifts $\delta g_{Lb},\ \delta g_{Rb},$

Collider bounds on heavy quarks suggest $Y_i \ll M_{1,2,3}$

Integrate out heavy fermions to obtain effective theory

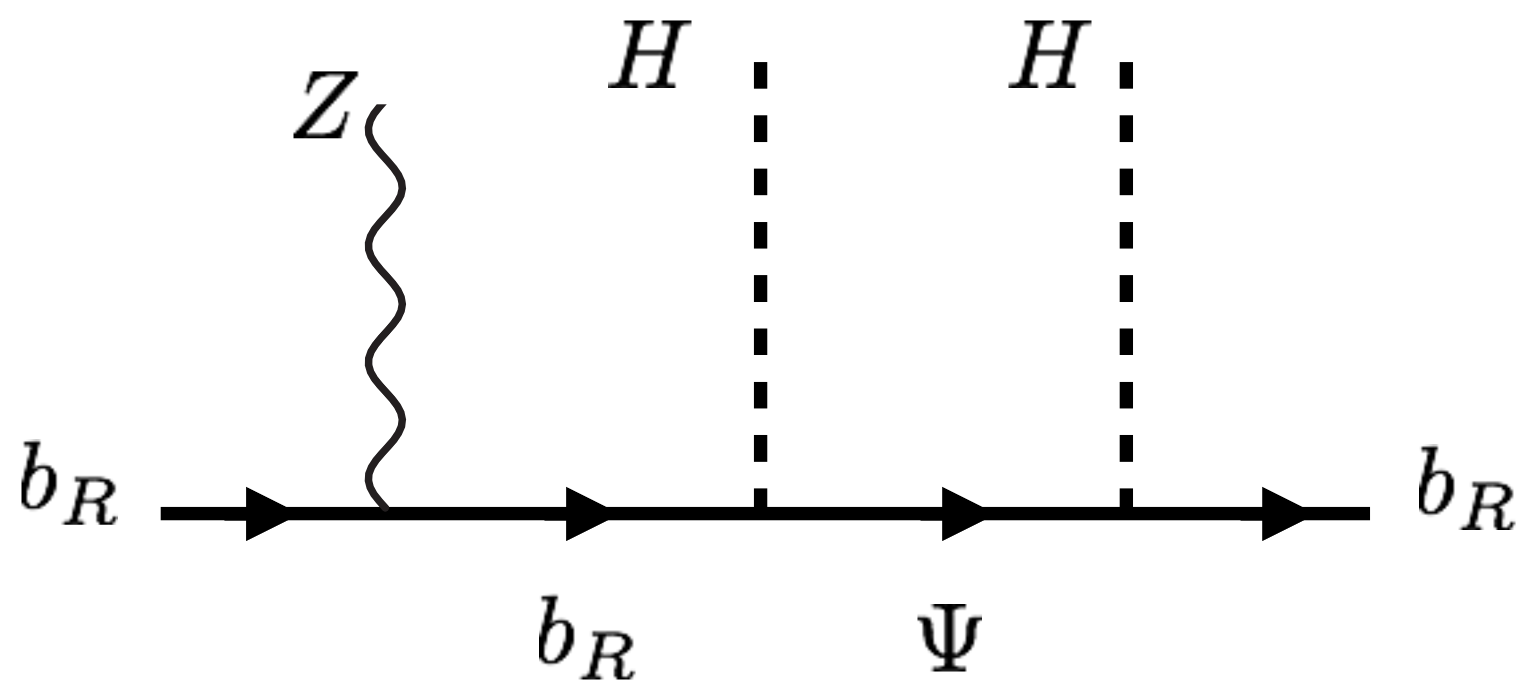
$$\mathcal{L} = \sum_i a_i \mathcal{O}_i$$

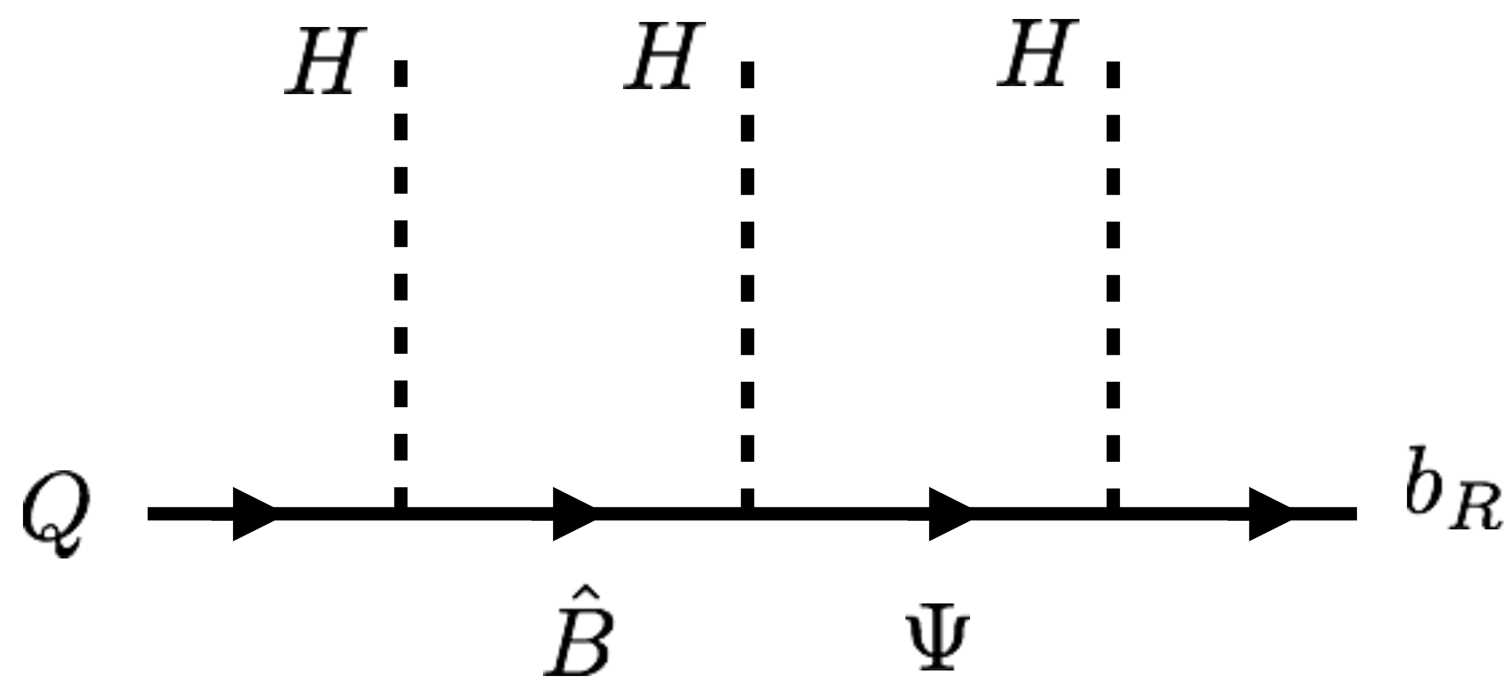
$$\left.\begin{aligned}
\mathcal{O}_{Hb} &= i(H^\dagger D_\mu H)(\bar{b}_R \gamma^\mu b_R) + \text{h.c.},\\
\mathcal{O}_{HQ}^s &= i(H^\dagger D_\mu H)(\bar{Q} \gamma^\mu Q) + \text{h.c.},\\
\mathcal{O}_{HQ}^t &= i(H^\dagger \sigma^a D_\mu H)(\bar{Q} \gamma^\mu \sigma^a Q) + \text{h.c.},
\end{aligned}\right\}$$

lead to shift in δg_{Lb}, δg_{Rb},

$$\mathcal{O}_{HY} = (H^\dagger H)(\bar{Q} H b_R) + \text{h.c.}. \quad \}$$

lead to shift in $m_b, y_{hb\bar{b}}$


Z
H
H
b_R
b_R
b_R
Ψ


H
H
H
Q
b_R
$\hat{B}$
Ψ

Non-universal $Zb\bar{b}$ shifts: $\delta g_{Lb} = \frac{Y_2^2}{2M_2^2}, \quad \delta g_{Rb} = \frac{Y_3^2}{2M_1^2}$

Recall $\delta g_{Rb} \sim 0.015, \quad \delta g_{Lb} \sim 0.001,$

$$Y_2 \simeq \pm 0.04\, M_2 \quad Y_3 \simeq \pm 0.17\, M_1$$

b - quark mass &

$h - b - \bar{b}$ coupling

$$m_b = Y_1 \left(1 - \frac{Y_2^2}{2M_2^2} - \frac{Y_3^2}{2M_1^2}\right) + \frac{Y_2 Y_3 Y_5}{M_1 M_2}$$

$$y_{hbb} = \frac{1}{v}\left[Y_1 \left(1 - \frac{3Y_2^2}{2M_2^2} - \frac{3Y_3^2}{2M_1^2}\right) + \frac{3Y_2 Y_3 Y_5}{M_1 M_2}\right]$$

$$r_b = \left(\frac{y_{hbb}}{m_b/v}\right)^2 \approx 1 + 8\sqrt{\delta g_{Rb}\delta g_{Rb}}\frac{Y_5}{m_b}$$

Large corrections to $h \to b\bar{b}$ possible only if Y_5 large

$h \to gg$ and $h \to \gamma\gamma$: Use low energy theorem

[Ellis, Gaillard, Nanopoulos `76]
[Shifman, Vainshtein, Voloshin, Zakharov `79]

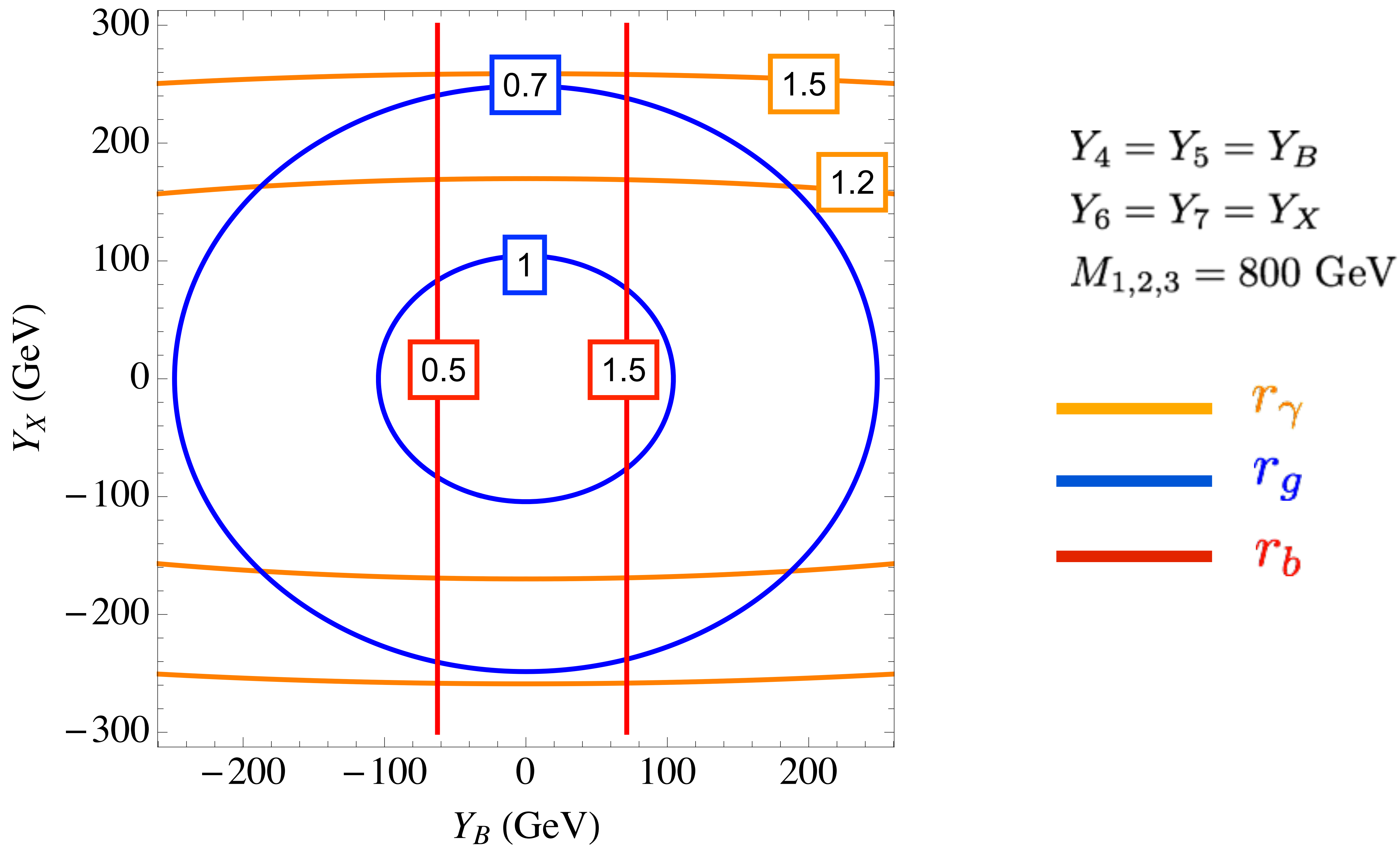
$$\mathcal{L} \supset \frac{\alpha}{16\pi v}\left[\sum_{f=B,X} b_f^{EM} z_f\right] h F_{\mu\nu}F^{\mu\nu} + \frac{\alpha_s}{16\pi v}\left[\sum_{f=B,X} b_f^c z_f\right] h G^a_{\mu\nu}G^{\mu\nu a},$$

$$b_B^{EM} = 4/9, \qquad b_X^{EM} = 64/9, \qquad b_B^c = b_X^c = 2/3.$$

$$z_f \equiv \frac{\partial}{\partial \log v}\left(\sum_i \log m_{f,i}^2(v)\right),$$

$$z_B \simeq -4\frac{Y_4 Y_5}{M_1 M_2} \qquad z_X \simeq -4\frac{Y_6 Y_7}{M_1 M_3}$$

$$r_\gamma \simeq \left|1 + 0.13\left(\frac{Y_4 Y_5}{M_1 M_2} + 16\frac{Y_6 Y_7}{M_1 M_3}\right)\right|^2 \quad , \quad r_g \simeq \left|1 - 2.1\left(\frac{Y_4 Y_5}{M_1 M_2} + \frac{Y_6 Y_7}{M_1 M_3}\right)\right|^2$$



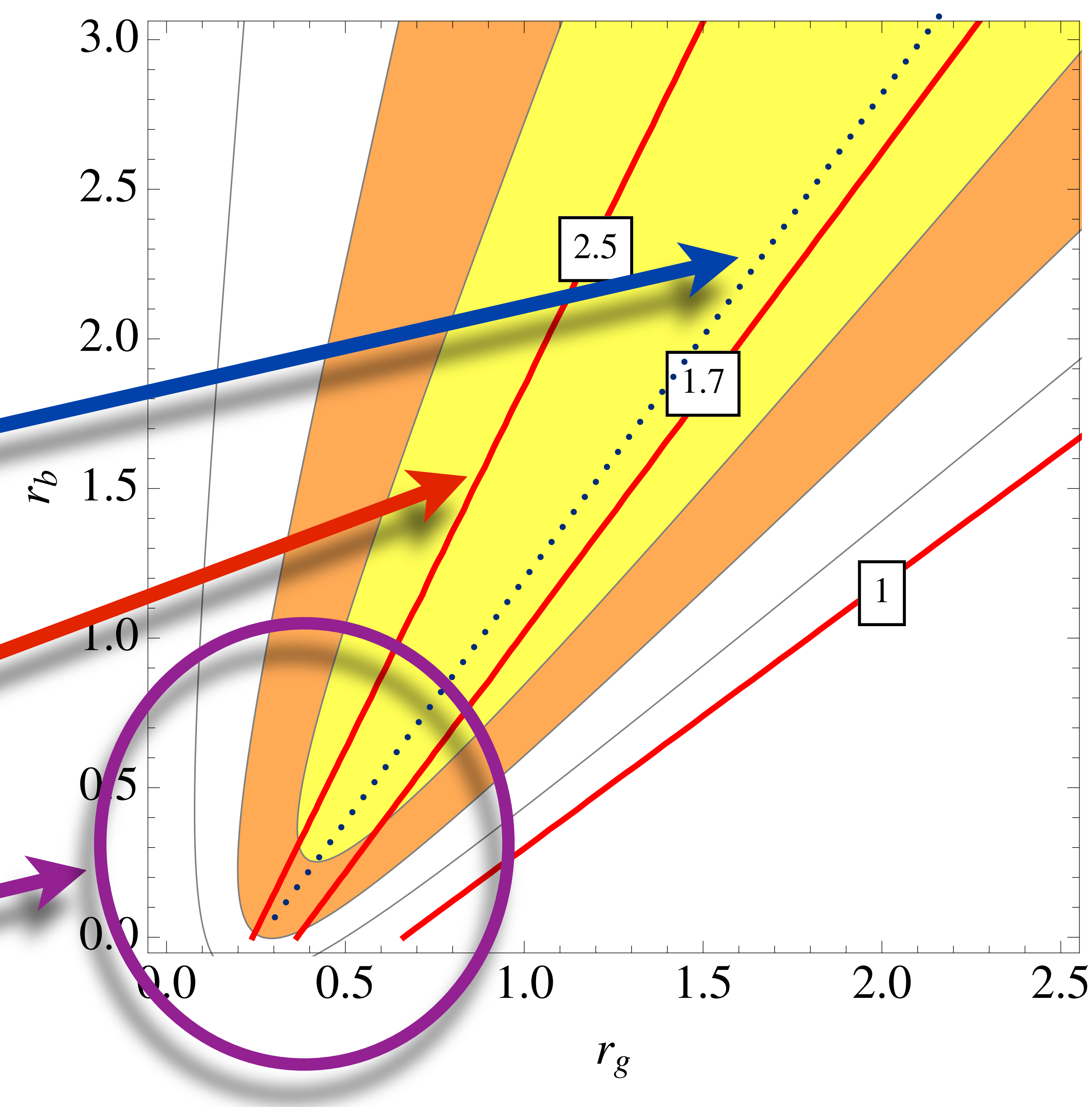
What does the signal strength data say?

$$\mu_{\gamma\gamma} \simeq \frac{r_g r_\gamma}{1+\mathrm{Br}_b(r_b-1)+\mathrm{Br}_g(r_g-1)},$$
$$\mu_{VV} \simeq \frac{r_g}{1+\mathrm{Br}_b(r_b-1)+\mathrm{Br}_g(r_g-1)},$$
$$\mu_{b\bar{b}} \simeq \frac{r_b}{1+\mathrm{Br}_b(r_b-1)+\mathrm{Br}_g(r_g-1)}$$

Shallow direction in $r_g - r_b$ plane

Marginalize over r_γ

The model lives in this region



Direct searches for Heavy Quarks

- Signatures similar to minimal $(3, 2, -5/6)$ model

[Kumar, Shepard, Tait, Vega-Morales '10]

- Most robust limit comes from top prime searches

CMS search in dilepton channel [CMS-EXO-11-050]

$$pp \to t'\bar{t}' \to (W^+b)(W^-\bar{b}) \to \ell^+\ell^-\nu\nu\bar{b}\bar{b}$$

Bounds masses heavier than $m_{t'} > 557$ GeV

- These bounds apply since X decays via $X \to bW^-$

Other possible decay mode $X \to BW^-$ requires

$m_X > m_B + m_W$, not favored by Higgs data (see shortly)

- Also bounds exist from bottom prime searches:

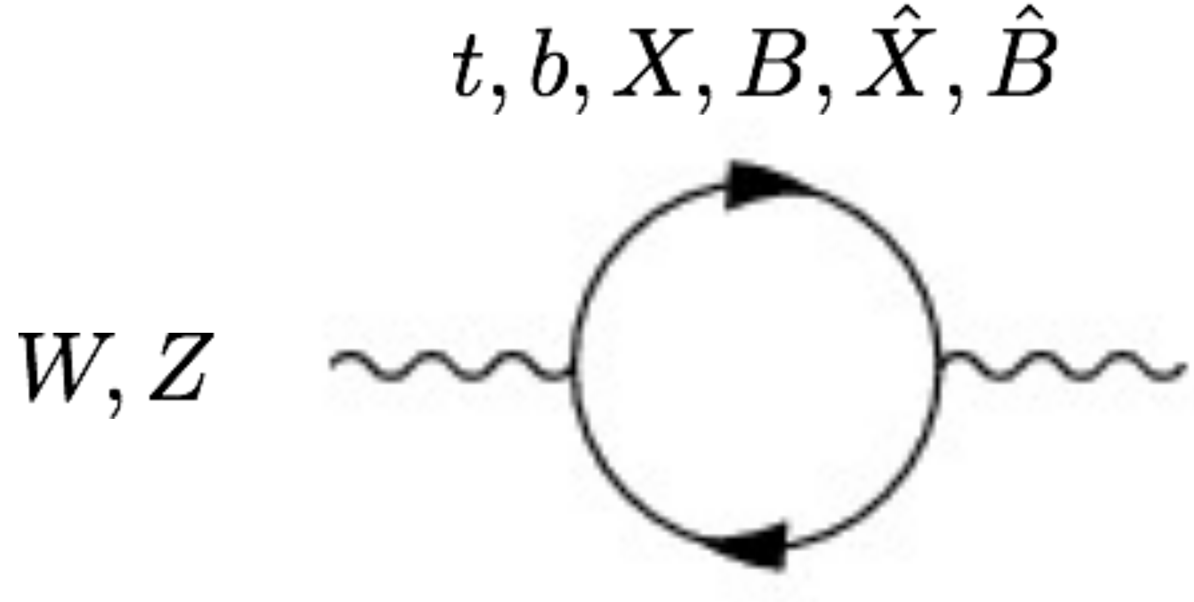
$$pp \to b'\bar{b}' \to W^-tW^+\bar{t} \to 4W2b \to 3\ell + b \text{ or SS } \ell + b$$

[CMS-EXO-11-036]

Bounds masses heavier than $m_{b'} > 611$ GeV

Oblique corrections

[Peskin, Takeuchi `90, `92]



- Contribution from new mirror quarks
- $W\bar{t}b, Z\bar{b}b$ vertices modified - include t, b and subtract off SM
- Restrict to 1σ regions determined by fit (including $\delta g_{L,R}$)

$$S = -0.02 \pm 0.09, \quad T = 0.03 \pm 0.08, \quad \rho \sim 0.90$$

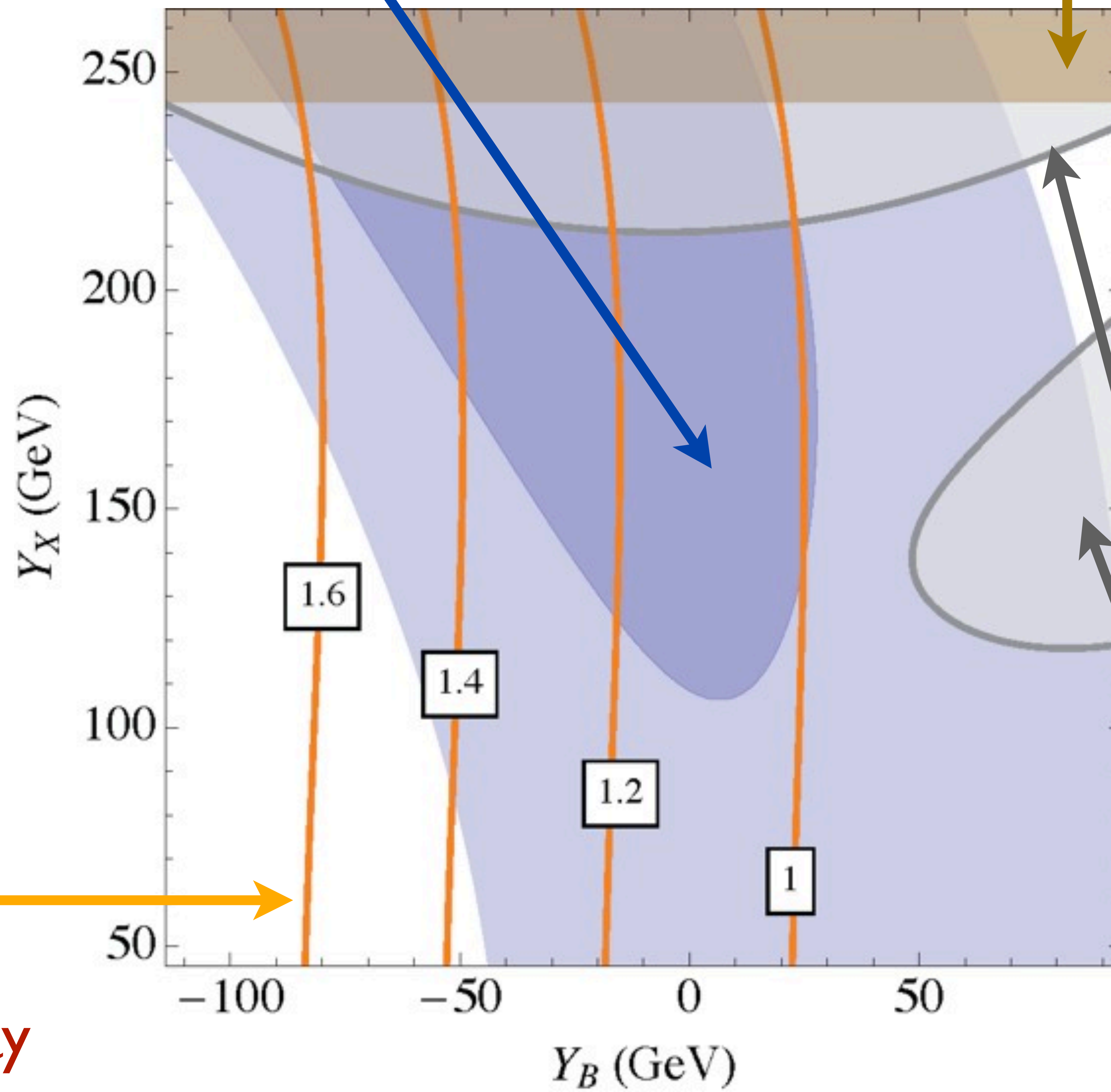
Results:

We have fixed

$$M_{1,2,3} = 800 \text{ GeV}$$
$$Y_{2,3} \leftrightarrow \delta g_{L,R}$$
$$Y_1 \leftrightarrow m_b$$
$$Y_4 = Y_5 = Y_B,$$
$$Y_6 = Y_7 = Y_X$$

Higgs signal strength $1\sigma, 2\sigma$ regions

top prime searches $M - Y_X < 557$ GeV



$\mu_{\gamma\gamma}$

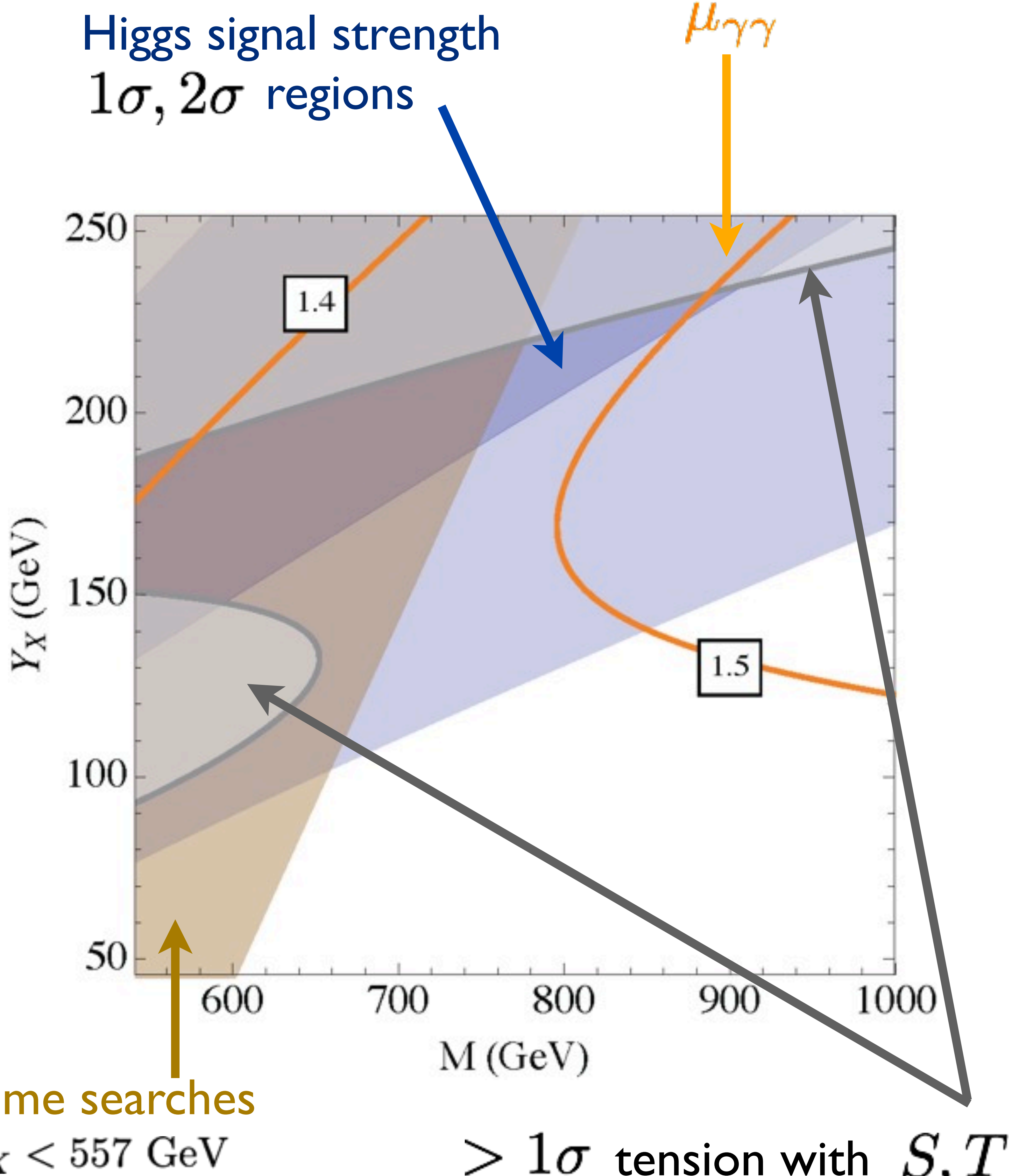
$> 1\sigma$ tension with S, T

Best-fit regions display enhancement $1 \lesssim \mu_{\gamma\gamma} \lesssim 1.6$

Results:

We have fixed

$$Y_{2,3} \leftrightarrow \delta g_{L,R}$$
$$Y_1 \leftrightarrow m_b$$
$$Y_4 = Y_5 = -65 \text{ GeV}$$
$$Y_6 = Y_7 = Y_X$$
$$M_1 = M_2 = M_3 = M$$



Caveat: Vacuum stability

As emphasized recently in several works, new fermions with O(1) Yukawa's drive Higgs quartic negative at low scale

Jogelkar, Schwaller, Wagner `12
Arkani-Hamed, Blum, D'Agnolo, Fan `12
Reece `12

In our model,

$$16\pi^2\beta_\lambda \simeq \quad 24\lambda^2 + 12\lambda(y_t^2 + y_4^2 + y_5^2 + y_6^2 + y_7^2) - 6(y_t^4 + y_4^4 + y_5^4 + y_6^4 + y_7^4)$$

e.g. $y_4 = y_5 = 0, y_6 = y_7 = 1;$ VL threshold $M = 800$ GeV

$\Rightarrow$ $\lambda = 0$ at $Q = 2$ TeV

- Model requires a UV completion to stabilize vacuum…
- Obvious candidate is a SUSY version (beyond scope here)

Outlook:

- 125 GeV Higgs discovered - as suggested by EW data
- Slight enhancement in $\mu_{\gamma\gamma}$, need more data
- Two discrepancies in EW data: $A_{FB}^{b}\,(2.6\sigma)$, $R_b\,(2.4\sigma)$
- Beautiful Mirrors - shift $Z\bar{b}_R b_R$ by $b - B$ mixing
- Mirror quarks can cause deviations in Higgs properties
- Model is testable at LHC via search for mirror quarks

Backup

Ingredients going into the electroweak fit:

- Observables

$$m_Z,\ \Gamma_Z,\ \sigma^0_{\rm had},\ R_\ell,\ R_c,\ R_b,$$
$$A^\ell_{FB},\ A_\ell,\ A_c,\ A_b,\ A^c_{FB},\ A^b_{FB},\ \sin^2\theta_{\rm eff},$$
$$m_W,\ \Gamma_W,\ m_t,\ \Delta\alpha^{(5)}_{\rm had},\ m_h$$

- Vary SM + NP parameters in fit

$$m_H, m_Z, m_t, \Delta\alpha^{(5)}_{\rm had}, \alpha_s,$$
$$S, T, \delta g_{Lb}, \delta g_{Rb}$$

- Theory predictions taken from various numerical parameterizations in literature...

2. A_{FB}^b, R_b due to systematic effect

EW data alone (w/o LHC Higgs mass measurement)

SM w/o A_{FB}^b, R_b :

$$p = 0.92$$
$$m_h = 70 \pm 30\ \text{GeV}$$

SM w/o A_{FB}^b, R_b
+ S, T, $m_h^{\text{ref}} = 125$:

$$p = 0.90$$
$$S = -0.08 \pm 0.10$$
$$T = 0.0 \pm 0.08$$

- Slight tension between indirect determination of Higgs mass (70 GeV) and 125 GeV
- New contribution to oblique parameters?

2. A_{FB}^b, R_b due to systematic effect

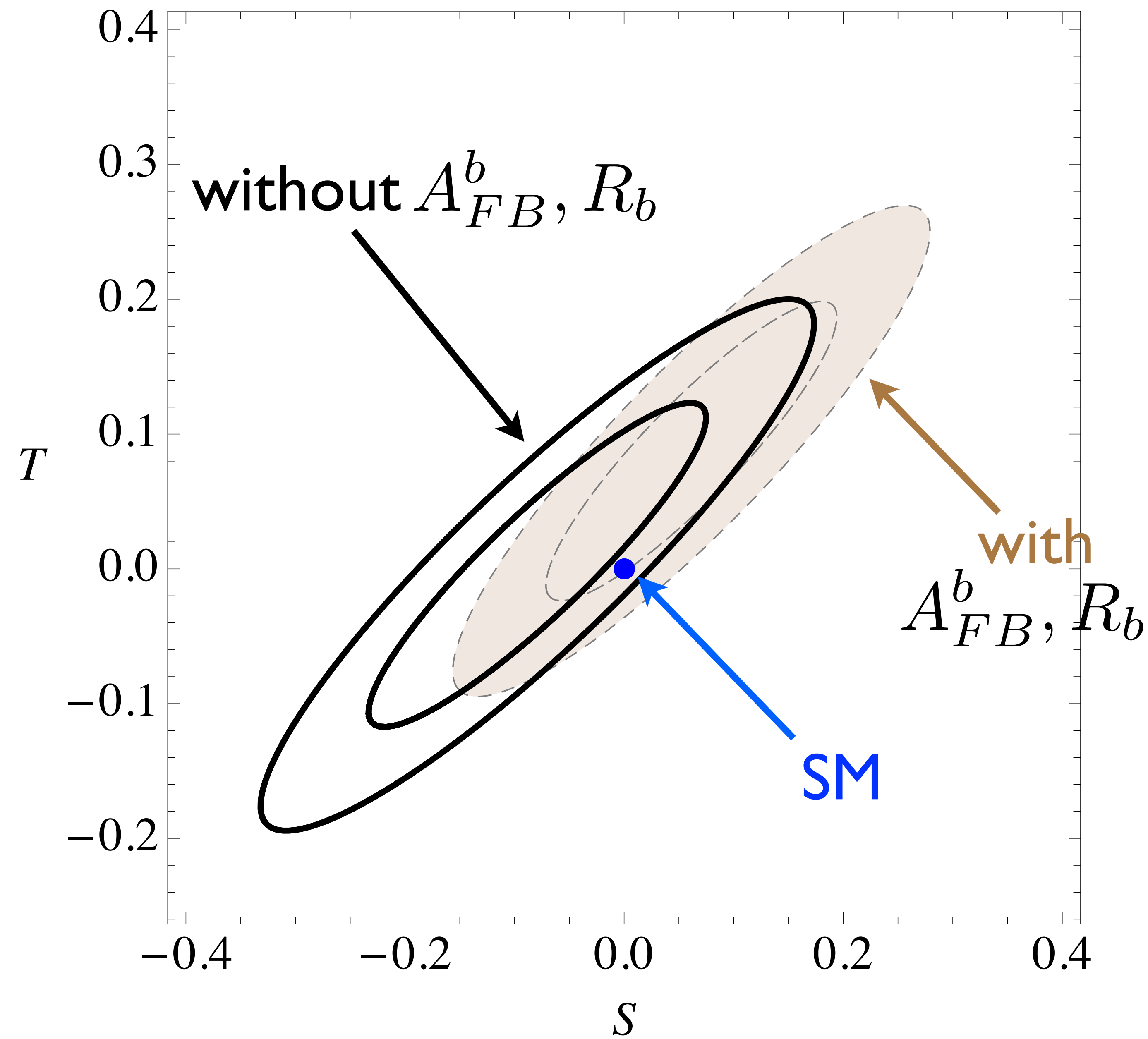
Including LHC Higgs mass measurement:

SM w/o A_{FB}^b, R_b :	$p = 0.67$ $m_h = 125.7$ GeV
SM w/o A_{FB}^b, R_b + S, T :	$p = 0.78$ $S = -0.08 \pm 0.10$ $T = 0.0 \pm 0.08$

- Marginal improvement with oblique parameters.
- No strong argument for new physics to pull up Higgs mass

$S - T$ fit

without A_{FB}^b, R_b



Electroweak fit (w/o A_{FB}^b, R_b)
marginally improved with non-zero S,T